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Identification of friction coefficient in high aspect ratio combined forward-backward extrusion with pulse ram motion on servo press

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Abstract

An extrusion method for forming deep holes is proposed with a servo press that utilizes a punch with an internal channel for the supply of liquid lubricant. In this forming method, the punch is pushed into the specimen with a servo press in a manner that combines pulsed and stepwise modes. Sufficient liquid lubricant is periodically supplied to the deformation zone through the internal channel upon the retreat of the punch. In this study, this forming method with pulse punch ram motion is applied to combined forward-backward extrusion process with a high aspect ratio. The coefficient of shear friction at the specimen–punch contact is identified by analyzing material flow of aluminum specimen during extrusion. The proposed forming method with appropriate pulse punch motion is confirmed to reduce the friction from the coefficient of shear friction of 0.4 to lower than 0.2.

Keywords: Forging; Extrusion; Friction; Servo press

1. Introduction

The programming of the ram speed and motion of servo presses with a servomotor through CNC control has led to new forming processes. Osakada et al. (2011) have reviewed servo press designs and their major applications in sheet metal forming and bulk metal forming processes. Concerning on friction in metal forming process with servo press, Maeno et al. (2011) reduced the friction in cold plate forging with a servo press by implementing load

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pulsation. Groche and Moller (2012) measured the friction in deep-drawing processes with a servo press that utilizes forming speed control. On the other hand, Matsumoto et al. (2011) have proposed an extrusion method for forming deep holes with a servo press that utilizes a punch with an internal channel for the lubricant supply. The concept of this forming method was derived from the machining of deep holes with tools that have internal channels. It has been demonstrated that this forming method prevents galling in the backward extrusion of holes with an aspect ratio (height/diameter) of six when the appropriate punch ram motions are applied. In addition, Matsumoto et al. (2013) have found that this forming method provides formed holes with high shape accuracy. However, the friction in this forming method with pulse punch ram motion has not previously been investigated.

It is difficult to directly measure the friction at the specimen–punch contact during forming with pulse punch ram motion. Sagisaka and Nakamura (2007) have proposed a testing method for determining the friction at the specimen–punch contact during combined forward-backward extrusion with aspect ratio of one. In this method, the friction was estimated from the material flow of the specimen in the forward and backward extruded parts. Murai et al. (2009) have examined the material flows of specimens during combined forward-backward extrusion with aspect ratios in the range 0.4–2.0, however, the material flow and friction in combined forward-backward extrusion with aspect ratios greater than two have rarely been examined.

In this study, the forming method with pulse punch ram motion is applied to combined forward-backward extrusion with a high aspect ratio. The relationship between the punch motion and the material flow of the aluminum specimen is investigated in extrusion with pulse punch ram motion. The friction is determined by analyzing the material flow of the specimen during extrusion with pulse punch ram motion by both experiment with a servo press and the finite element analysis.

2. Extrusion with pulse punch ram motion

2.1. Combined forward-backward extrusion method

The extrusion method for reducing the friction over the punch surface is shown in Fig. 1 (Matsumoto et al. (2011)). The punch with an internal channel for lubricant flow is pushed into the specimen in a manner that combines pulsed and stepwise modes and assists the supply of liquid lubricant from the punch nose. The punch is connected to a lubricant tank, and the lubricant is supplied to the internal channel from the tank. During forming with a manner that combines pulsed and stepwise modes, the internal pressure in the cavity formed in the previous forming steps is depressurized by the retreat of the punch, and the lubricant is sucked into the cavity through the internal channel (Fig. 1(b)). In this method, no pump and/or check valve for the prevention of backward flow is used in the supply of the lubricant from the punch nose. The lubricant is sucked into the deformation zone because of the change in the internal pressure in the cavity. After the retreat of the punch, the punch is advanced again to continue the forming of the hole (Fig. 1(c)). Each advance of the punch can be carried out without seizure because sufficient lubricant is supplied to the forming zone during the retreat of the punch.

To describe the punch motion, the following parameters are defined:

n_{total}: total number of forming steps

$s_{\mathrm{a}i}$: advance stroke in the i-th forming step (i = 1 to n_{total})

$s_{\mathrm{r}i}$: retreat stroke in the i-th forming step (i = 1 to n_{total})

$s_{\mathrm{f}i}$: forming stroke in the i-th forming step ($= s_{\mathrm{a}i} - s_{\mathrm{r}i}$) ($i$ = 1 to n_{total})

s_{total}: total forming stroke of the punch ($= \sum_{i=1}^{n_{\mathrm{total}}} s_{\mathrm{f}i}$)

In this study, $s_{\mathrm{a}i}$, $s_{\mathrm{r}i}$, and $s_{\mathrm{f}i}$ were set as constant. Thus, $s_{\mathrm{a}i}$, $s_{\mathrm{r}i}$, and $s_{\mathrm{f}i}$ can be written as s_{a}, s_{r}, and s_{f}, respectively.

2.2. Experimental conditions

The tool arrangement for the forming method is shown in Fig. 2. The punch with an internal channel for lubricant flow was connected to the lubricant tank by a tube. The punch diameter was D_{P} = ϕ6.0 mm, and the diameters of the internal channel were D_{I} = ϕ1.5 mm at the inside of the channel and ϕ0.5 mm at the output of the channel. A counter punch with diameter D_{CP} = ϕ4.5 mm was prepared to examine the material flow of the specimen in the forward and backward extruded parts. There was no internal channel for lubricant in the counter punch. The inner diameter of the container was D_C = ϕ9.0 mm. The extrusion ratios for the forward and backward parts were 1.33 and 1.80, respectively. The materials used for the punches and container were high speed tool steel (HRC63–65) and matrix high speed tool steel (Hitachi Metals, Ltd., YXR3, HRC59–62), respectively. The punches and container surfaces were polished to a mirror finish with Ra = 0.02–0.04 μm. The initial dimensions of the specimen was ϕ8.9 mm in diameter and L_0 = 30 mm in height. The specimen material was an AA6061-T6 aluminum alloy. Mineral oil with a kinematic viscosity of 32 mm^2/s (at 40 ºC) was used as the lubricant.

The tools were installed on a 450 kN servo press (Komatsu Industrial Corp., H1F45). The punch position–time and speed–position diagrams for the retreat and advance pulse ram motion are shown in Fig. 3. The total step number (n_{total}) was limited to less than five because of the press specifications. The forming stroke in every forming step was set in the range s_f = 6–24 mm (s_f/D_P = 1.0–4.0), and the total forming stroke of the punch was fixed as s_{total} = 24 mm (s_{total}/D_P = 4.0). The retreat stroke of the punch in every forming step was fixed as s_r = 6 mm (s_r/D_P = 1.0) because it was confirmed that sufficient lubricant (approximately 18 mm^3, nominal thickness: 110 μm) entered the forming zone during the retreat action of the punch in condition of $s_r/D_P \geq 0.5$ (Matsumoto et al. (2013)). The average forming speed range was v_{avg} = 20–80 mm/s. To investigate the influence of the total forming duration on the forming characteristics of the combined forward-backward extrusion, a punch ram motion with (s_f = 24 mm, n_{total} = 1, and v_{avg} = 20 mm/s) was tested. The total forming duration of the punch ram motion was the same as that of a pulse punch ram motion with (s_f = 6 mm, n_{total} = 4, and v_{avg} = 20 mm/s).

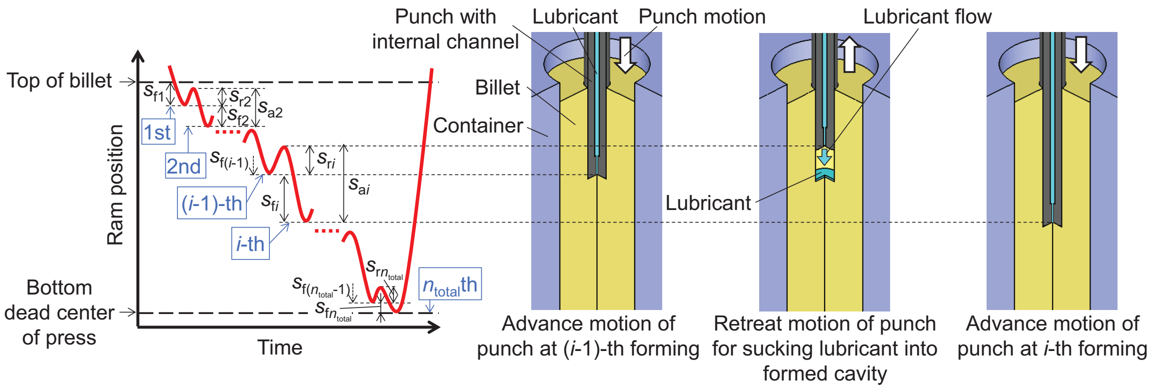

Fig. 1. Retreat and advance pulse ram motion of a punch with an internal channel for pulsating lubricant supply (s_{ai}: advance stroke of punch in i-th forming step, s_{ri}: retreat stroke of punch in i-th forming step, s_{fi}: forming stroke of punch in i-th forming step, i = 1 to n_{total}).

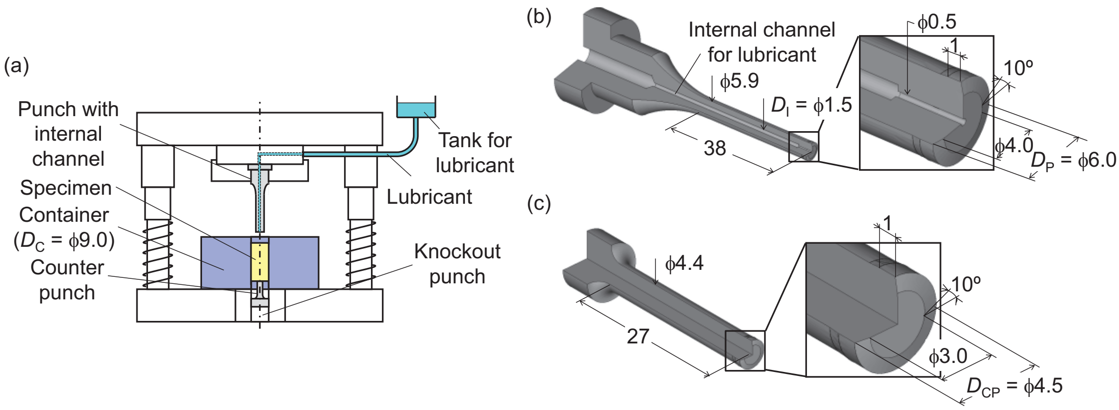

Fig. 2. Schematic illustrations of tool arrangement and punches for combined forward-backward extrusion: (a) tool arrangement (D_C: inner diameter of container); (b) punch with an internal channel of lubricant (D_P: punch diameter, D_I: diameter of internal channel); (c) counter punch (D_{CP}: counter punch diameter).

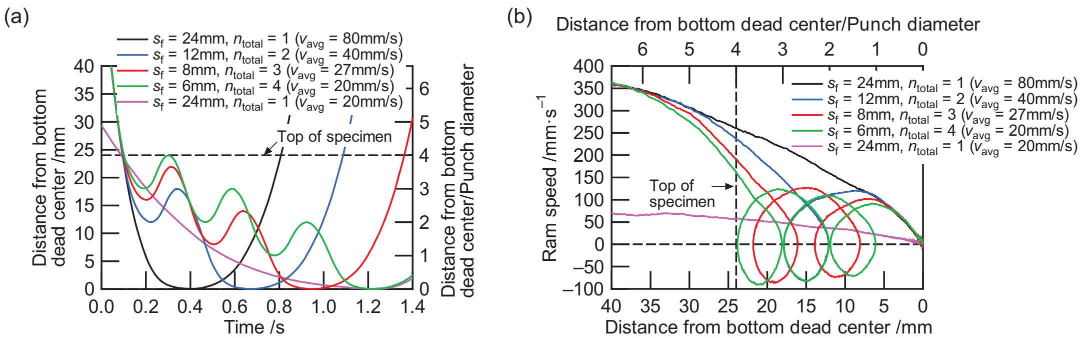

Fig. 3. Punch position–time and speed–position diagrams for retreat and advance pulse ram motion on a servo press (total forming stroke: s_{total} = 24 mm, v_{avg}: average forming speed): (a) punch position–time; (b) punch speed–diagram.

2.3. Finite element analysis conditions

To analyze the material flow of the specimen during combined forward-backward extrusion with pulse punch motion, a finite element analysis was carried out by employing a commercial elastic-plastic finite element analysis code (Simufact Engineering GmbH, simufact.forming ver.11). In this simulation, the elastic-plastic deformation and temperature change in the aluminum specimen were calculated with two-dimensional axisymmetric analysis. The dies were assumed to be rigid bodies. The dimensions, geometries, and temperatures of the specimen and the dies used in the finite element simulation were identical to the experimental values. The punch ram motions shown in Fig. 3 were employed. The flow stress of the AA6061-T6 aluminum alloy was measured at various temperatures by the upsettability test. Since the friction condition at the specimen–punch contact was strongly affected by the supplied amount of lubricant, the friction condition was assumed to be specified by the coefficient of shear friction m_P = 0–1.0, and the coefficients of shear friction at the specimen–counter punch and specimen–container contacts were assumed to be fixed as 0.2. The heat transfer coefficients for the specimen–die contact and the free surfaces of the specimen were determined with heating and cooling tests to be 10000 $W{\cdot}m^{-2}{\cdot}K^{-1}$ and 20 $W{\cdot}m^{-2}{\cdot}K^{-1}$, respectively. The specific heat capacity and the thermal conductivity of the specimen were assumed to be constant (no consideration with temperature dependency) from the literature (Japan Aluminium Association, 2001).

3. Results

3.1. Galling at formed hole surface in experiment

Fig. 4 shows the surface roughness of the sidewall of the backward extruded hole obtained with combined forward-backward extrusion with s_{total}/D_P = 4.0 with pulse punch motion. Galling of the hole surface was caused by the sliding of the punch during the advance and/or retreat of the punch. Since the surface roughness with pulse punch motions of $s_f/D_P \le 2.0$ was lower than that with a no pulse punch motion of s_f/D_P = 4.0, the pulse punch motion is confirmed to be effective to reduce the surface roughness. Galling occurred in forming with a pulse punch motion of $s_f/D_P \ge 2.0$. A hole with a smooth surface (no galling) was formed by the appropriate pulse punch motions. The maximum forming stroke of the punch for preventing galling at each forming step in the forming with pulse punch motion is found to be s_f/D_P = 1.3.

3.2. Material flow in experiment

It is well-known that the material flow of a specimen in combined forward-backward extrusion is strongly affected by the friction at the specimen–punch contact (Sagisaka and Nakamura (2007)). Low friction at the specimen–punch interface means that the specimen tends to be extruded to backward, whereas high friction at the specimen–punch contact means that the specimen tends to be extruded forward. Fig. 5 shows the material flows of the specimen during combined forward-backward extrusion of $s_{total}/D_P = 4.0$ with pulse punch motion with/without lubricant supply to the internal channel of the punch. When the lubricant was not supplied to the internal channel of the punch, the backward extruded length tended to be shorter due to high friction and galling at the specimen–punch contact than that obtained with lubrication. Furthermore, the backward extruded length decreased with decreases in the forming stroke (s_f) under dry forming condition. Since the total sliding distance of the specimen–punch contact was long in the pulse punch motion, high friction and heavy galling were considered to be caused, especially in the dry pulse forming with $s_f/D_P < 2.0$. When the lubricant was supplied to the internal channel of the punch, the specimen tended to be extruded backward in the forming with $s_f/D_P < 2.0$. This result means that the lubricant is periodically supplied to the forming zone by the retreat action of the punch and that the extrusion is successfully conducted under good lubrication state.

3.3. Material flow in finite element analysis

Fig. 6 shows the relationship between the extruded length of the specimen and the coefficient of shear friction at the specimen–punch contact for combined forward-backward extrusion with $s_{total}/D_P = 4.0$. As mentioned in section 3.2, the backward extruded length increased with decreases in the friction, whereas the forward extruded length increased with increases in the friction.

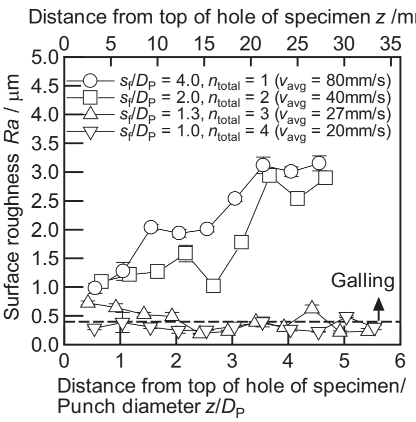

Fig. 4. Influence of punch motion on the surface roughness of the backward extruded hole in combined forward-backward extrusion with pulse punch motion ($s_{total}/D_P = 4.0$).

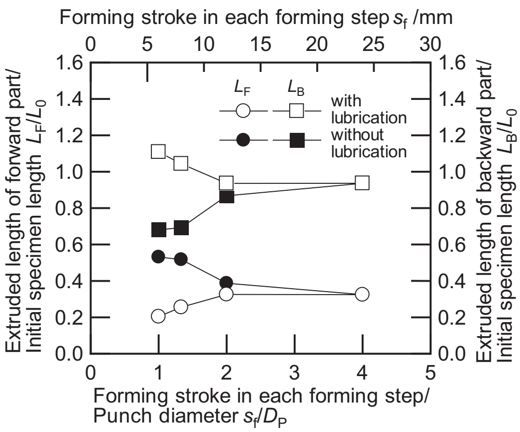

Fig. 5. Influence of punch motion on material flow of aluminum specimen during combined forward-backward extrusion with pulse punch motion ($s_{total}/D_P = 4.0$).

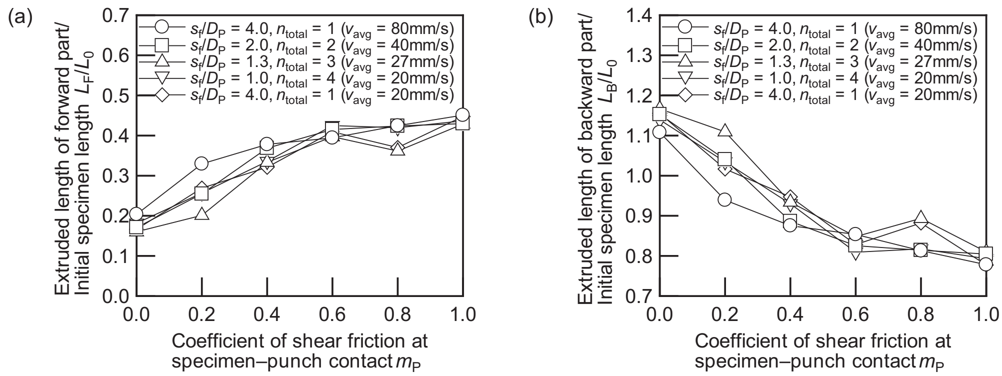

Fig. 6. Relationship between the formed specimen shape and the coefficient of shear friction at the specimen–punch interface ($s_{total}/D_P = 4.0$) (finite element simulation): (a) forward part; (b) backward part.

4. Discussion

The nominal coefficient of shear friction at the specimen–punch interface (m_P) was determined by comparing the experimental extruded lengths (Fig. 5) and the results obtained with finite element analysis (Fig. 6). The determined coefficient of shear friction is shown in Fig. 7. The coefficients of shear friction determined from the forward and backward extruded lengths were almost the same. The coefficient of shear friction for forming without lubricant (dry condition) was higher than that for forming with lubricant. In forming without lubricant, the coefficient of shear friction for the pulse punch motion was higher than that without pulse punch motion because heavy galling was caused in the formed hole, as discussed in section 3.2. In contrast, a low coefficient of shear friction arose in forming with the pulse punch motion and lubricant because good lubrication state was maintained during forming by the periodic supply of lubricant to the forming zone. Thus the forming method with appropriate pulse punch motion is confirmed to reduce the friction at the specimen–punch contact.

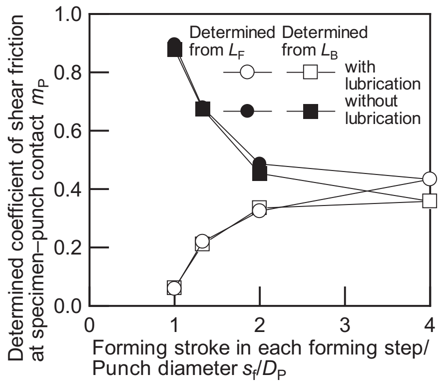

Fig. 7. Relationship between determined coefficient of shear friction at the specimen–punch contact and punch ram motion during combined forward-backward extrusion with pulse punch motion.

5. Conclusion

A forming method with pulse punch motion was applied to combined forward-backward extrusion with a high aspect ratio. The coefficient of shear friction at the specimen–punch contact with pulse punch motion was determined from experimental results with a servo press and the finite element analysis results. The proposed forming method with appropriate pulse punch motion reduced the friction between the specimen and the punch with an internal channel for lubricant to the coefficient of shear friction lower than 0.2 because sufficient liquid lubricant to prevent galling was periodically supplied to the deforming zone through the internal channel during the retreat action of the punch.

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